Forecasting the air pollution episode potential in the Canary Islands

C. Milford, C. Marrero, C. Martin, J. J. Bustos, X. Querol

Adv. Sci. Res., 2, 21–26, 2008
www.adv-sci-res.net/2/21/2008/

Advances in Science and Research

7th EMS Annual Meeting and 8th European Conference on Applications of Meteorology 2007

Forecasting the air pollution episode potential in the Canary Islands

C. Milford[1,2], C. Marrero[2], C. Martin[2], J. J. Bustos[2], and X. Querol[1]

[1]Institute of Earth Sciences "Jaume Almera", CSIC, Barcelona, Spain
[2]Izaña Atmospheric Research Center, Agencia Estatal de Meteorología, Tenerife, Spain

Received: 27 December 2007 – Revised: 19 March 2008 – Accepted: 1 April 2008 – Published: 9 April 2008

Abstract. In the frame of the WMO Global Atmosphere Watch Urban Research Meteorology and Environment programme (GURME), a system for forecasting air pollution episode potential in the Canary Islands has been developed. Meteorological parameters relevant to air quality (synoptic wind speed, wind direction, boundary layer height and temperature at 91 vertical levels) are obtained from the European Centre for Medium range Weather Forecasting (ECMWF) once a day for up to four days ahead. In addition, a model based on the analogue method utilising six years of historical meteorological and air quality data predicts the probability of SO_2 concentration exceeding certain thresholds for a measurement station located in Santa Cruz de Tenerife. Meteorological forecasts are also provided from a high resolution (2 km) local area model (MM5) implemented for the Canary Islands domain. This simple system is able to forecast meteorological conditions which are favourable to the occurrence of pollution episodes for the forthcoming days.

1 Introduction

The adverse effects of ambient air pollution on health are well studied (e.g., Brunekreef and Holgate, 2002; Samet and Krewski, 2007). As a consequence the European Union introduced the Air Quality Directive (1999/30/EC) establishing hourly, daily and annual limit values for various air pollutants and a requirement to provide the public with up-to-date information on air concentrations. In addition to providing "real-time" concentrations many countries and public authorities worldwide now also provide forecasts of air quality.

The Canary Islands benefit from trade winds dispersing and transporting pollutants over the ocean. However, this is only the case for a proportion of the time and the islands do experience pollution episodes in certain meteorological conditions due to both local anthropogenic sources (an oil refinery, power stations and substantial road and sea traffic) and natural sources (African Dust Intrusions). Consequently, a system to forecast air pollution episode potential in the Canary Islands was developed. The Canary Islands have a complex topography, as shown for Tenerife in Fig. 1, which interacts with the prevailing synoptic conditions to create mesoscale and microscale meteorological phenomena (e.g. sea and mountain slope breezes, stagnant conditions). These conditions provide a challenge to meteorological forecasters and also to air quality forecasting in the archipelago.

Air quality forecasting can be performed with statistical (e.g., Nunnari et al., 2004) or deterministic methods (e.g., Grell et al., 2005; Otte et al., 2005) and there are advantages and limitations to both approaches. Deterministic methods require sufficient computing resources and high resolution emission inventories; such an inventory is not currently available for the Canary Islands. Consequently, statistical methods were chosen for this first approach to air pollution episode potential forecasting in the Canary Islands, utilising measured air quality data and meteorological data output from the European Centre for Medium-Range Weather Forecasts (ECMWF). The work presented here focuses on predicting meteorological conditions which are favourable to the development of pollution episodes due to local anthropogenic sources. Pollution episodes due to African Dust Intrusions are a regional scale phenomenon and are forecasted in a complementary system (Alonso-Pérez et al., 2004).

2 Study area

The Canary Islands are one of the regions of Spain, situated in the Atlantic Ocean off the western coast of Morocco. Tenerife and Gran Canaria are the most populated islands

Correspondence to: C. Milford
(cmilford@inm.es)

Published by Copernicus Publications.

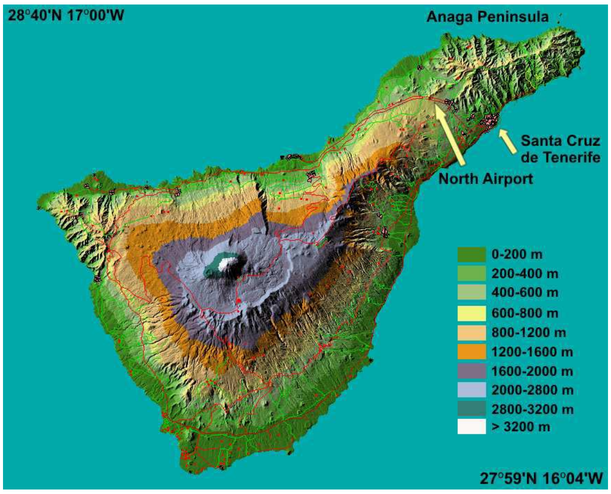

Figure 1. Topographic map of Tenerife (from Carta Digital v2.0).

in the archipelago; their populations in 2006 were 853 000 and 807 000, respectively (ISTAC, 2007). For the purpose of brevity this paper concentrates only on data for Santa Cruz de Tenerife, the capital of Tenerife. Santa Cruz de Tenerife is located in the NE of the island (Fig. 1) on a SE facing slope ranging from 0 to 624 m a.s.l. at the North Airport. It is also bordered by the Anaga peninsula situated to the NE which reaches an altitude of 992 m. The oil refinery is located in Santa Cruz de Tenerife.

3 Materials and methods

3.1 Air quality and meteorological data

The air quality data used in this study consisted of hourly ambient concentrations of SO_2, NO and NO_2 obtained for the period 1/1/1999 to 31/12/2004 from various monitoring stations in Santa Cruz de Tenerife (see Table 1). The stations were operated by the Department for Control of Industrial Emissions (CEI) and the Department of Public Health of the Canary Islands Government and the Izaña Atmospheric Research Center.

Meteorological parameters were obtained from the ECMWF numerical weather prediction model reanalysis at six hourly intervals (00:00, 06:00, 12:00 and 18:00 UTC for a single grid point to the north-east of Tenerife (29°15′ N 15°45′ W) for the same six-year period. The parameters included wind u and v components (m s^{-1}) at 1000 hPa, boundary layer height (BLH) (m) and temperature (K) at 60 vertical levels. A measure of the atmospheric stability was derived from the integral of the potential temperature data from $H=0$ to $H=1500$ m and denoted Integrated Stability Potential (EPI):

$$\mathrm{EPI} = \frac{1}{H}\int_0^H (\theta(z) - \theta(0))\, dz.$$

Table 1. Measurement station details (U: Urban; UB: Urban Background; SCO: Santa Cruz Observatory).

Station	Location	Altitude (m)	Type
Casa Cuna	28°26′58″ N 16°16′41″ W	180	U
Viera y Clavijo	28°27′48″ N 16°15′37″ W	40	U
Tome Cano	28°27′49″ N 16°15′39″ W	75	U
Los Gladiolos	28°27′35″ N 16°16′01″ W	95	U
SCO	28°28′21″ N 16°14′50″ W	52	UB

The meteorological data was interpolated with the Cubic Splines method to provide hourly data to be consistent with the temporal resolution of the air quality data.

3.2 Models

3.2.1 Analogue method

The analogue method is a simple statistical technique based on searching for an analogue to a target variable (predictor) in a historical dataset. Once the analogue of the predictor is found in the historical dataset, the corresponding predictand (the variable of interest) at this time is selected. It is a technique that has been widely used to predict meteorological variables such as precipitation in both forecast mode (Obled et al., 2002) and in downscaling studies (e.g., Zorita and von Storch, 1999; Wetterhall et al., 2005).

An implementation based on the analogue method which is successfully used to predict precipitation in the Canary Islands (Marrero and Bustos, 2003) was adapted to predict the probability of exceedance of SO_2 concentration thresholds for the Tome Cano measurement station in Santa Cruz de Tenerife. The predictors used in the model were daily (12:00 UTC) geostrophic wind fields calculated from the geopotential at 500 hPa and 1000 hPa from the ECMWF reanalysis and analysis for the period 1999–2004. The domain selected was 20.250 to 36.0° N, 3.375 to 27.125° W with a resolution of 1.125°.

In forecast mode, 100 days (analogues) are selected from the six year dataset according to their similarity with the forecasted geostrophic wind fields and this group is reduced to 30 days after selecting those with the most similar atmospheric stability value. The pseudo-euclidean distance is used to numerically select the analogues, for more details see (Marrero and Bustos, 2003). The weighted median and 99th percentile of SO_2 concentration of these 30 days are calculated and the probabilities of exceeding the 70th and 80th percentile of the six year SO_2 concentration dataset are evaluated.

3.2.2 PSU/NCAR mesoscale model (MM5)

The Fifth-Generation Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model (MM5) is a high resolution, nonhydrostatic, limited area model (Grell et al., 1994). The resolution of the ECMWF numerical weather prediction model is 25 km. In order to gain information at a higher spatial resolution it was decided to implement MM5 for the Canary Islands. The model is run with a mother domain of 18 km resolution centered at 28.34° N and 16.45° W and two-way nested grids of 6 and 2 km. Hourly forecasts of wind speed and wind direction at 10 m, temperature, precipitation, cloud cover and boundary layer height are provided for two days ahead.

4 Results

4.1 Relationship of pollution episodes with meteorological conditions

The ambient air concentrations of SO_2, NO and NO_2 at the different measuring sites were analysed for the six year period and pollution episodes identified. The relationship of the pollutant concentrations to the meteorological parameters obtained from ECMWF at the single grid point (see Sect. 3.1) was analysed during these pollution episodes. One such pollution episode occurred during 22–28/4/2002, SO_2, NO and NO_2 concentrations during this episode are shown in Fig. 2a and b while Fig. 2c shows the temporal evolution of the ECMWF variables. All values presented are hourly mean values except for BLH which are daily values at 12:00 UTC.

On 18 and 19/4/2002 the boundary layer height at 12:00 was ≈1150 m and the EPI values were low. The pollutant concentrations during these days were at a low level; the mean hourly concentrations of SO_2 and NO_2 at Los Gladiolos measurement station for 18–19/4/2002 were 11 μg m^{-3} and 15 μg m^{-3}, respectively. On 20/4/2002 the BLH started to decrease, reaching a minimum value of 100 m on 23 and 24/4/2002. Meanwhile the stability increased, reaching a maximum EPI value on the night of 23/4/2002. After this date the BLH started to increase gradually and the EPI decreased. SO_2 concentrations at Tome Cano and Los Gladiolos were enhanced throughout 22–27/4/2002. The maximum hourly SO_2 concentration at Tome Cano was 275 μg m^{-3} and occurred in the early hours of the morning of 24/4/2002. NO and NO_2 concentrations at Los Gladiolos were also noticeably enhanced during 22–27/4/2002, the maximum hourly NO_2 concentration reached 91 μg m^{-3} at 20:00 on 23/4/2002. These maximum concentrations coincided with the maximum stability and minimum boundary layer height.

Analysis of other periods of high pollutant concentrations in the six-year dataset confirmed the importance of the boundary layer height and atmospheric stability in determining pollution episodes in the Canary Islands. This is a result that has been observed in other studies. Hooyberghs et al. (2005) concluded that the boundary layer height was the most important input variable for their neural network forecast of daily average PM_{10} concentrations while Kukkonen et al. (2005) found that the temporal evolution of temperature inversions and atmospheric stability were the key meteorological predictors of air pollution episodes in four European cities (Helsinki, London, Milan and Oslo).

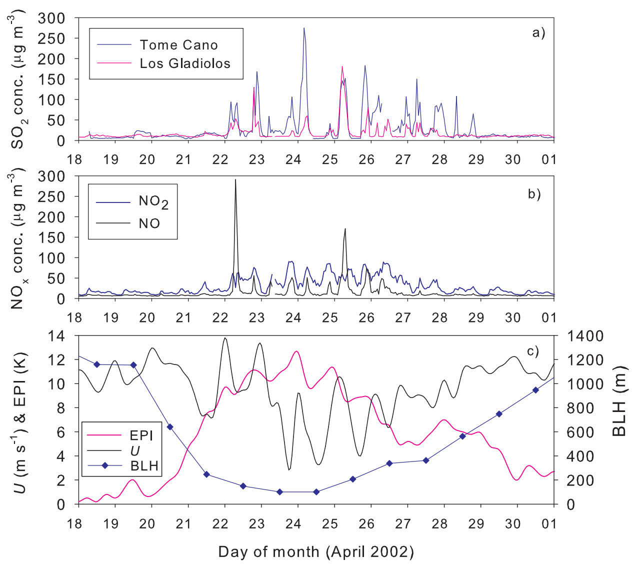

Figure 2. Mean hourly concentrations of **(a)** SO_2, **(b)** NO and NO_2 at Los Gladiolos and **(c)** stability (EPI), wind speed (U) and boundary layer height (BLH) from ECMWF reanalysis, 18–30 April 2002.

The relation of pollutant concentrations with model wind speed, however, was not so clear. Although the wind speed decreased during 23–25/4/02, in general the wind speed was not low during this period. When examining the whole dataset, a correlation between pollutant concentrations and model wind speed was not found (data not shown). This confirmed the need for a higher resolution model such as MM5.

4.2 High resolution MM5 forecast

An example of the MM5 wind speed forecast at 10 m for the nested grid at 2 km resolution is shown in Fig. 3 for 29/7/2007 at 08:00 h and 14:00 h. This day was characterised by an extremely low inversion layer and boundary layer height (see Fig. 4) with a moderate to strong wind speed from the NE. The Anaga peninsula provides an obstacle to the wind field when such a low inversion layer is present and stagnant conditions can occur in Santa Cruz de Tenerife. This local stagnation is demonstrated by the MM5 forecast at 08:00 h; the wind speed in Santa Cruz de Tenerife is low (<4 km/h) even though the synoptic wind strength to the NE is moderate to strong. At 14:00 h this is no longer the case, at this time there is a component of the wind towards the land surface. This is caused by the land heating effect modifying the synoptic wind direction towards the land surface. These mesoscale wind phenomena affect the dispersion and transport of pollutants and coupled with a strong inversion layer can lead to significant pollution episodes in Santa Cruz de Tenerife and the surrounding area.

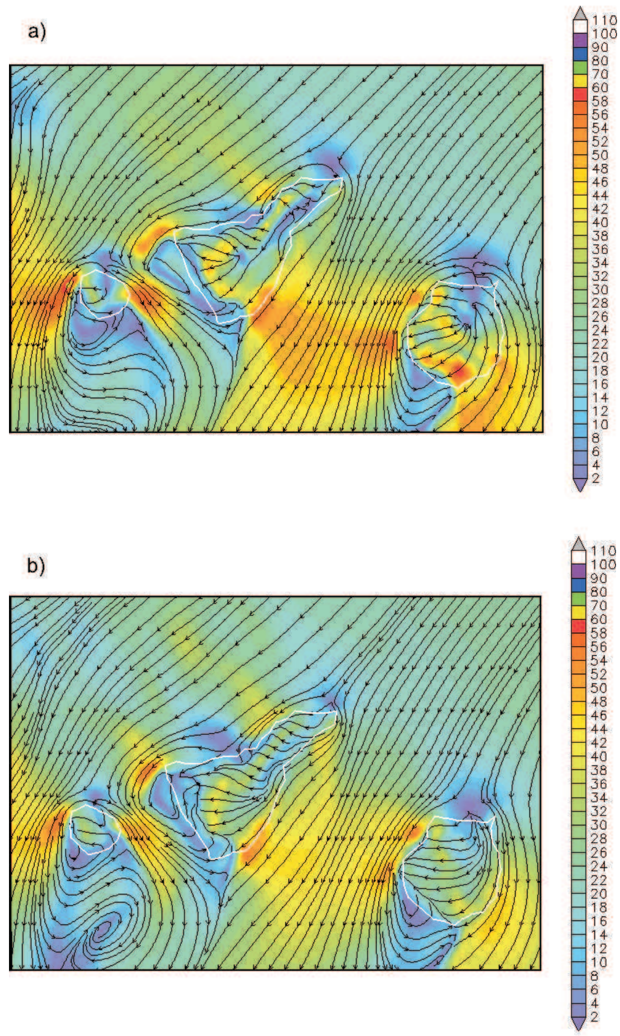

Figure 3. MM5 wind speed forecast (km/h) and streamlines for Tenerife, La Gomera and Gran Canaria (2 km resolution) at 10 m a.s.l. for 29/7/2007 at **(a)** 08:00 and **(b)** 14:00.

5 Air Pollution Episode Potential Forecast System

The Air Pollution Episode Potential Forecasting System is based on automatic retrieval of the meteorological parameters described in Sect. 3.1 (synoptic wind speed, wind direction, boundary layer height and temperature at 91 vertical levels) from the ECMWF forecasts at intervals of 6 h up to 108 h ahead. In 2006, the number of vertical levels in the ECMWF model was changed from 60 to 91. These meteorological parameters are displayed on a daily basis in a convenient table format (Fig. 4). The analogue model is also executed daily for up to four days ahead and the outputs displayed in the same format.

The percentile range of the six-year dataset in which the ECMWF data point lies is indicated in the table by the colour of the table entry. For example, for BLH the colours represent that the forecasted data point lies within the following percentile ranges: green (>P75), yellow (P50 to P75), orange (P25 to P50) and red (<P25). If the BLH values are in the lowest percentile range and the EPI values are in the highest percentile range, coupled with a high probability of the SO_2 concentration of the analogue model exceeding 70th and 80th percentiles then this indicates high Pollution Episode Potential on a synoptic scale. If this is the case, the MM5 forecasts are examined in more detail and if the predicted local wind speed and wind direction are also considered favourable towards a pollution episode (based on data analysis and experience) a Pollution Episode Warning is issued.

Meteorological influences on air quality occur on various scales, ranging from the synoptic scale to the mesoscale and local scale. Consequently, it is necessary to assess the influences on these different scales. This is achieved in the forecasting system by considering both the ECMWF data as displayed in the automatic table (representative of the synoptic scale) and the MM5 output (representative of the mesoscale).

An example of the automatic table of predicted meteorological parameters is shown in Fig. 4 for 26–30/7/2007. On 26/7/2007 the EPI values and the boundary layer and inversion layer height values were in the mid-range. However, the EPI was predicted to increase and the BLH and inversion height decrease at the end of this day. The predicted EPI continued to increase in the following days until reaching a maximum on the night of 28–29/7/07, while the BLH reached extremely low values (<100 m). Such high EPI values and low BLH indicate high Pollution Episode Potential and this was also reflected in the values of the analogue model. Pollution Episode Warnings were issued on 27/7–1/8/2007.

SO_2 concentrations from the Tome Cano (urban) and Santa Cruz Observatory (urban background) measurement sites are shown in Fig. 5a for the period 25/7–3/8/2007. This demonstrates that a pollution episode did occur during this period. The SO_2 concentration at both sites started to increase on 27/7/07 and reached a maximum of 430 $\mu g\,m^{-3}$ at Tome Cano on 27/7/07 and of 341 $\mu g\,m^{-3}$ at SCO on 28/7/2007. The concentrations exceeded both the EU hourly (350 $\mu g\,m^{-3}$) and daily limit value (125 $\mu g\,m^{-3}$). The analogue model prediction of the probability of the SO_2 concentration at Tome Cano exceeding the 80th percentile is also presented in Fig. 5a and this increases during 27–31/7/2007. Figure 5b shows the evolution of the EPI and the Boundary Layer Height values during this period. NO and NO_2 concentrations also increased during this period (data not shown). Future work will involve a full validation of the analogue model and assessment of the performance of the Air Pollution Episode Potential Forecasting System.

6 Conclusions

An Air Pollution Episode Potential Forecasting System has been presented for the Canary Islands. This is based on

FECHA	HORA	DIR	ROSA	VEL	EPI	BLH	B_INV	C_INV	T_BAS	T_CIM	MEDIAN	PER99	>%70	>%80
26-07-2007	00	023	NNE	8.6	6.2	590	518	1305	15.8	22.5	*****	*****	**	**
26-07-2007	06	022	NNE	9.5	5.7	654	639	1304	15.6	22.6	*****	*****	**	**
26-07-2007	12	021	NNE	8.6	6.5	521	518	1308	17.3	23.5	10.0	739.0	34	16
26-07-2007	18	019	NNE	9.6	8.1	422	318	1314	18.5	25.2	*****	*****	**	**
27-07-2007	24	029	NNE	10.5	8.8	418	318	1123	19.0	26.0	*****	*****	**	**
27-07-2007	30	032	NNE	11.2	8.7	432	411	1121	18.9	26.4	*****	*****	**	**
27-07-2007	36	042	NE	10.2	10.4	346	319	1129	20.2	28.7	12.0	318.0	46	42
27-07-2007	42	036	NE	11.4	11.5	312	320	1133	21.1	30.1	*****	*****	**	**
28-07-2007	48	043	NE	11.7	12.7	288	241	796	21.4	31.4	*****	*****	**	**
28-07-2007	54	051	NE	9.5	12.2	220	321	957	22.2	31.7	*****	*****	**	**
28-07-2007	60	054	NE	9.7	12.9	188	118	797	22.8	32.1	22.0	357.0	54	52
28-07-2007	66	041	NE	11.3	13.9	180	72	801	23.2	32.9	*****	*****	**	**
29-07-2007	72	047	NE	11.9	15.0	201	118	658	23.0	34.1	*****	*****	**	**
29-07-2007	78	064	ENE	9.0	14.0	132	13	37	23.5	23.6	*****	*****	**	**
29-07-2007	84	070	ENE	8.5	14.4	89	13	803	23.4	34.5	26.0	357.0	63	55
29-07-2007	90	056	ENE	10.3	14.6	124	12	660	24.0	35.2	*****	*****	**	**
30-07-2007	96	053	NE	11.7	14.4	151	13	661	24.3	35.0	*****	*****	**	**
30-07-2007	102	061	ENE	9.4	12.8	135	13	802	24.4	32.9	*****	*****	**	**
30-07-2007	108	062	ENE	9.2	13.2	100	13	805	24.3	33.1	26.0	357.0	68	60

Figure 4. Example of automatic table of predicted meteorological parameters retrieved daily from ECMWF and results from the analogue model for 26–30/7/2007. Wind direction (DIR) (°), wind direction component (ROSA), wind speed (VEL) ($m\,s^{-1}$), Integrated Stability Potential (EPI) (K), boundary layer height (BLH) (m), lower and upper heights of inversion (BINV, CINV) (m), temperature at lower and upper boundary of inversion (TBAS, TCIM) (°C), median and 99th percentile of SO_2 conc. of analogues (MEDIAN, PER99), probability of SO_2 conc. exceeding 70th and 80th percentiles (>%70, >%80) (%). The colours represent the percentile range of the six-year dataset in which the datapoint lies: (<P_{25}), (P_{25} to P_{50}), (P_{50} to P_{75}) and (>P_{75}). Depending on the parameter the colours (green, yellow, orange and red) indicate ascending (e.g. EPI) or descending values (e.g. wind speed and BLH).

expert assessment of the values of meteorological parameters obtained from ECMWF forecasts, on a novel application of a model based on the analogue method which predicts the probability of SO_2 concentration exceeding thresholds for a measurement station located in Santa Cruz de Tenerife and on forecasts of the PSU/NCAR mesoscale model, MM5. This simple system is able to forecast meteorological conditions which are favourable to the occurrence of pollution episodes for up to 108 h ahead. The implementation of MM5 for the Canary Islands domain at 2 km resolution provides crucial information, in particular concerning the predicted behaviour of the mesoscale wind phenomena in the archipelago and the interactions with the complex topography of the islands. It serves as a complementary and additional tool to the synoptic forecasts provided by ECMWF.

Clearly improvements to the system can be made and future work will involve exploring other advanced statistical methods for Air Quality Forecasting such as Artificial Neural Networks and also development of deterministic methods coupled with MM5. It would also be of interest to expand the forecasting system to explicitly include other pollutants such as NO, NO_2 and O_3, this would require the consideration of other meteorological parameters such as solar radiation. In addition, increasing the MM5 forecasts to three days ahead would improve the air quality forecasting capability.

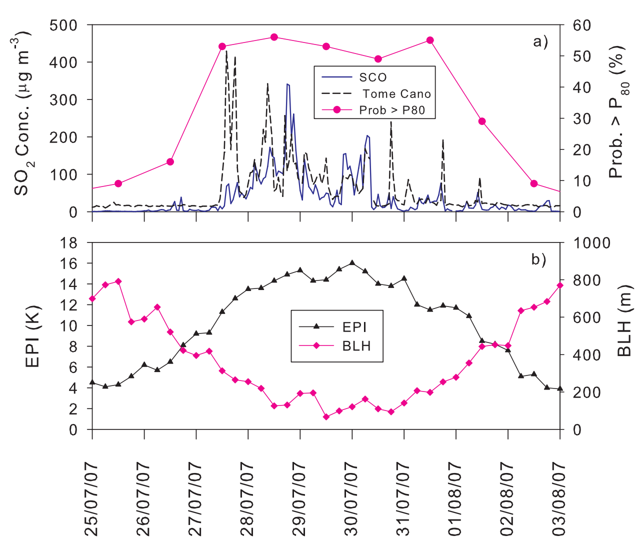

Figure 5. **(a)** Mean hourly concentrations of SO_2 at the Santa Cruz Observatory (SCO) and Tome Cano and analogue model prediction of the probability of the SO_2 concentration at Tome Cano exceeding the 80th percentile (P_{80}) for 25/7-3/8/2007, **(b)** six hourly values of Integrated Stability Potential (EPI) and Boundary Layer Height (BLH) during the same period.

Acknowledgements. The authors gratefully acknowledge funding from the Spanish Ministry of Education and Science through the Juan de la Cierva Program (Orden ECI/158/2005, BOE) and from the Viceconsejería de Medio Ambiente del Gobierno de Canarias. We also would like to thank colleagues of the Izaña Atmospheric Research Center, in particular Yenny Gonzalez-Ramos funded by the Agencia Estatal de Meteorología for access to data at the Santa Cruz Observatory and CEI (Viceconsejería de Medio Ambiente) and Dirección General de Salud Pública for data from their Air Quality Monitoring Networks.

Edited by: S. Joffre
Reviewed by: two anonymous referees

References

Alonso-Pérez, S., Pey, J., Cuevas, E., Querol, X., Alastuey, A., Romero, P. M., and Cristobal, A.: Sistema de información sobre intrusiones de masas de aire africano en España, in: Proceedings of the IX Congreso de Ingeniería Ambiental PROMA 2004, Bilbao, Spain, 10–12 November 2004, 621–629, 2004.

Brunekreef, B. and Holgate, S. T.: Air pollution and health, Lancet, 360, 1233–1242, 2002.

Grell, G. A., Dudhia, J., and Stauffer, D. R.: A description of the fifth-generation Penn State/NCAR mesoscale model (MM5), NCAR Technical Note, NCAR/TN-398+STR, 117 pp., 1994.

Grell, G. A., Peckham, S. E., Schmitz, R., McKeen, S. A., Frost, G., Skamarock, W. C., and Eder, B.: Fully coupled "online" chemistry within the WRF model, Atmos. Environ., 39, 6957–6975, 2005.

Hooyberghs, J., Mensink, C., Dumont, G., Fierens, F., and Brasseur, O.: A neural network forecast for daily average PM10 concentrations in Belgium, Atmos. Environ., 39, 3279–3289, 2005.

Instituto Canario de Estadística (ISTAC): Anuario Estadístico de Canarias: 2006, Gobierno de Canarias, 2007.

Kukkonen, J., Pohjola, M., Sokhi, R. S., Luhana, L., Kitwiroon, N., Fragkou, L., Rantamäki, M., Berge, E., Odegaard, V., Slordal, L. H., Denby, B., and Finardi, S.: Analysis and evaluation of selected local-scale PM10 air pollution episodes in four European cities: Helsinki, London, Milan and Oslo, Atmos. Environ., 39, 2759–2773, 2005.

Marrero, C. and Bustos, J. J.: Adaptación para Canarias de un modelo de predicción estadística de la precipitación mediante un método analógico, in: Proceedings of the Primer Encuentro sobre Meteorología y Atmósfera de Canarias, Tenerife, Spain, 12–14 November 2003, 107–109, 2003.

Nunnari, G., Dorling, S., Schlink, U., Cawley, G., Foxall, R., and Chatterton, T.: Modelling SO_2 concentration at a point with statistical approaches, Environ. Modell. Softw., 19, 887–905, 2004.

Obled, C., Bontron, G., and Garcon, R.: Quantitative precipitation forecasts: a statistical adaptation of model outputs through an analogues sorting approach, Atmos. Res., 63, 303–324, 2002.

Otte, T. L., Pouliot, G., Pleim, J. E., Young, J. O., Schere, K. L., and Mathur, R.: Linking the Eta Model with the Community Multiscale Air Quality (CMAQ) modeling system to build a national air quality forecasting system, Weather Forecast., 20, 367–384, 2005

Samet, J. and Krewski, D.: Health effects associated with exposure to ambient air pollution, J. Toxicol. Env. Heal. A, 70, 227–242, 2007.

Wetterhall, F., Halldin, S., and Xu, C. Y.: Statistical precipitation downscaling in central Sweden with the analogue method, J. Hydrol., 306, 174–190, 2005.

Zorita, E. and von Storch, H.: The analog method as a simple statistical downscaling technique: Comparison with more complicated methods, methods, J. Climate, 12, 2474–2489, 1999.